ASTERIAS: AUTOMONOUS SAILBOAT FOR TITAN EXPLORATION AND RECONNAISSANCE OF LIGEIA SEA William J. O'Hara IV[1], [1]NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058

Introduction: Sailing the oceans of Earth has served as a means of exploration and transportation for over 2000 years. Our fascination with sailing continues today as an activity enjoyed by many people in many countries. This capability can serve us again in the exploration of alien worlds. Titan, the icy moon of Saturn, has surface seas despite its frigid climate. Could mankind sail the seas of Titan?

While composed of liquid Methane instead of water, the hydrologic cycle surrounding these seas mirrors Earth's in unexpected ways. The observation of dendritic valley networks supports the theory of a surface drainage system [6]. The Huygen's probe found an atmosphere humid in methane and capable of generating methane rain [1]. All these factors lead to the discovery of a hydrologic cycle similar to Earth but with Methane as the operating fluid instead of water [5]. This system has created sea depths up to 200 meters in Ligeia Mare. Additionally, evidence for waves has been provided by Cassini. This observation confirmed the existence of winds over the seas [9]. With adequate depth and available wind, a sailing vessel is an obvious option for exploring this fascinating world.

Challenges of Titan: Robotic sailboats, referred to as ASVs, sailbots or saildrones, are a recent development. They have been the subject of conferences and competitions since 2005 [8]. The ASV designs involved have focused on vessel lengths from 1 m to 4m long. However, sailing the seas of Titan will be very different from a terrestrial ASV mission. The combination of atmospheric composition and pressure, surface gravity, methane properties and predicted wind speeds result in a unique sailing environment.

Surface temperatures on Titan average approximately -180C. At this temperature water ice is hard as rock. Methane and ethane exist as ice and liquid, instead of gasses as they do on Earth's surface. These temperatures are colder than that experienced by rovers and landers on Mars. Also in contrast to rover missions on Mars, direct contact with the sea will cause higher heat loss through conduction.

The density of liquid methane is 42% of the density of liquid water. While the lower density fluid will provide for ease of movement, it can also be a hindrance. For example, it will affect stability of the ASV by providing less dampening for rocking motions. It also will have an affect on the ship's volumetric displacement when afloat. The lower gravity of Titan, 14% of Earth's, acts to counter this issue, however. A 1000 lb vessel would only displace 140 lbs, or 5.3 ft^3, of methane versus the same displacement on Earth requiring 16 ft^3 of water. This means the ASV will float much higher on Titan than it would on Earth, a fact that will require a change from traditional boat design.

In 2014 researchers analyzing radar data from Cassini noticed changes in surface roughness of all three major seas from one pass of the moon to another indicating the presence of waves [9]. It turns out that most of the recent studies of Titan have occurred during the winter season in northern hemisphere. Spring arrived in the northern hemisphere around 2010 and in 2016 the season is now in mid-summer. Researchers predict the potential for these winds to reach up to 45 mi/hr during the long northern summer season [4] [2]. Given the effect of the seasons on the observed winds it is proposed that the next optimal timing for the ASTERiaS mission will be the next-late spring to-mid summer. As the seasons change every 7 years, the next mid-summer will not be until the 2040's.

Analyses and Model Development: This investigation will analyze Titan's atmosphere and sea conditions in order to derive key ASV design requirements and mature its operations concept. The combination of atmospheric composition and pressure, surface gravity, methane properties and predicted wind speeds result in a unique sailing environment that will need to be fully understood. This investigation will include modeling of sail performance and sizing, as well as ship stability and maneuverability in conditions never before experienced by a sailing vessel. In addition to analyses of factors driving sailboat design and performance the thermal environment will be analyzed to the first order to characterize the thermal control challenge. The culmination of this work will be to sufficiently understand the variables involved in order to generate a conceptual Titan sailboat design.

A key analysis will be the performance of the ASV as a sailboat. Industry standard design ratios involving displacement, length and sail area will be reassessed to determine optimum values. The prismatic coefficient, which is used to design the shape of the boat's hull, is a ratio of displacement versus hull cross-section [7]. As these rations were developed for terrestrial sailboat design they will need to be reassessed for conditions on Titan. Additionally, in order to control the ship's direction it must have sufficient lateral resistance [7]. The hull design will need to compensate for the low displacement, which acts to reduce the lateral resistance gained by the profile of the submerged hull. Also related to performance is the location of the sail's center of effort in relation to the hull's center of lateral resistance [3]. These two must be in balance. A change in hull shape to address displacement driven issues will have side affects on the location of the center of lateral resistance.

More factors to be assessed include the static and dynamic stability resulting from the changes in displacement discussed earlier. A terrestrial boat would float higher and thus have a higher freeboard, raising its center of gravity and reducing its stability [7]. This would become and issue when the boat heels (rolls to one side). Since a space mission is by nature weight and volume limited, the ASTERiaS ASV will not have the luxury of a lead weighted keel to provide stability when heeling.

The necessary analysis to develop the ASTERiaS ASV amounts in many ways to rewriting the manual for sailboat design. Everywhere gravity, fluid density, air density, and temperature is a factor must be reassessed. For example, the surface air pressure on Titan is 1.45 atm – or 45% greater than surface pressure on Earth, and with the temperature so much colder, the density of air on the surface of Titan is about 4.5 times that of Earth. For a given area of sail, the lift and drag forces vary directly with air density. A component of the lift generated by the sail pulls the ship forward. Here we find that a sail on Titan would have 4.5 times more lift capability than on Earth. This would indicate that sails used on Titan can be much smaller than might initially be assumed. This is an important area of further study because the smaller the sail and mast have to be the less mass and volume they will need.

Development of a Conceptual Design: Armed with an understanding of the sailboat performance and ship stability in the environment and sea conditions of Titan, a conceptual design for an ASTERiaS ASV will take shape.

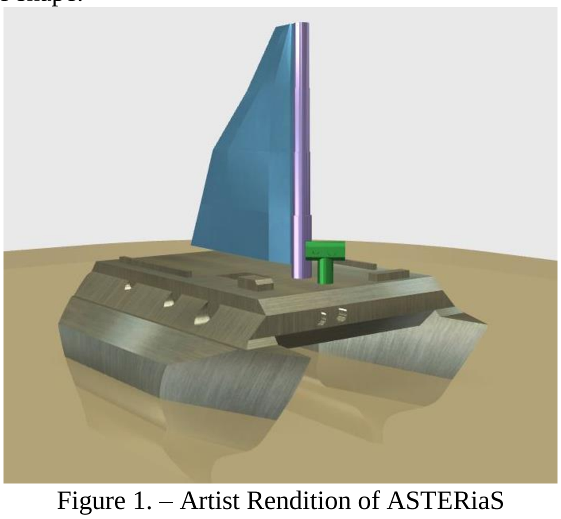

Figure 1. – Artist Rendition of ASTERiaS

Two key trade studies which drive the vehicle architecture is that of hull design and sail design. Many factors discussed here are greatly influenced by the choice between monohull or multihull options and the corresponding hull shape. Likewise, the choice for sail design will drive sailing capability, performance, and speed. The developed design parameters will be used in these trade studies, as well as all of the vehicle subsystems.

A key benefit of the ASTERiaS ASV platform is the variety of sensor suites and science packages that may be employed. The ASV provides locations on the hull below the fluid line, on the deck, as well as elevated above the deck on the sail or mast. Sensors and cameras located in these various locations will allow reconnaissance of the sea floor, subsurface, above surface (including nearby objects such as icebergs, islands and coasts) as well as sky observation. Weather sensors, subsurface SONAR and cameras, above surface RADAR and cameras as well as sampling systems and spectrometry systems are all in consideration for inclusion in this vehicle.

Conclusion: The implementation of a sailing probe would represent a whole new advancement in planetary exploration similar to how the wheeled rover was an advancement from the stationary lander. Recent research has verified the depth of the seas and the existence of surface winds, making an Autonomous Sailing Vessel a viable option for future exploration of Titan. Recent proposals for follow-on probes from Huygens have been for drifter [11] or submarine style designs [10]. A sail would provide a lower power means of locomotion than required for a submarine, and improve the probe's versatility and reach over the drifter design. This investigation proposes to analyze the Titan environment for all factors affecting the design and performance of a sailing vessel and develop new requirements for its design. Employing this mode of travel, used for thousands of years here on Earth, on an alien word embodies with it a piece of ourselves, and our ancestors. It is fitting that the means of travel used by early explorers to cross our oceans to find new lands be used to explore new worlds.

References:

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